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DIURNAL VARIATION OF THE INCIDENCE OF MONSOON RAINFALL OVER THE SUDAN (PART I)

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Summary. Using 15 years' data from 17 autographic rain-gauges in the Sudan, the diurnal variation of the incidence of monsoon rainfall has been tabulated by months. The considerable differences in space and time are systematic and reveal clearly defined patterns. These patterns are discussed in terms of the likely mechanisms for rainfall growth and suppression. Day-time convection, leading to a maximum incidence during the afternoon or early evening, is dominant only at places distant from the Ethiopian highlands. Elsewhere, rainfalls are more evenly distributed throughout the day, with weak maxima possible at any time, depending on location and month. However, an early morning maximum occurs widely. The Ethiopian highlands appear to influence the diurnal patterns in several ways and over distances of hundreds of kilometres.

Introduction. There is still a widely held opinion that tropical rains fall most frequently in the afternoon and evening, and that they are a result of the well-known diurnal cycle of convection. However, evidence is accumulating to show that the maximum incidence can occur at any time of day, and that the timing can vary considerably over short distances. As examples, reference may be made to descriptive studies from Africa[1,2] and southern Asia.[3–5]

In the Sudan, it has long been known[6–8] that rain at Khartoum falls most frequently during the hours of darkness, particularly between sunset and midnight, and that this pattern changes little throughout the period of significant rainfall, May to October. Oliver[9] states that around Khartoum most rain falls at night, whereas in the western Sudan there is a concentration between midday and sunset. Ireland[10] gives the late afternoon or early evening as a general time of maximum rainfall frequency.

Over the Sudan, away from the Red Sea coast, rainfall is effectively confined to a definite season. In the extreme south of the country, for example at Juba (Figure 1), average monthly falls of 0·1 inch (2·5 mm) or more occur in every month of the year,[11] but further north at Malakal the rainy season lasts only from March to November. Further north still, the season becomes progressively shorter: at Khartoum it extends from May to October, at Atbara from July to September, whilst at Wadi Halfa the very scanty rains fall mostly in July and August. The length of the rainy season at a given

locality depends upon the duration there of the equatorial westerlies. These winds of the lower troposphere blow to the south of the intertropical convergence zone (ITCZ), whilst above about 2 km winds are easterly up to the tropopause. North of the ITCZ, the north-easterly trades blow at low levels. Only the westerlies contain moisture sufficient for the formation of rain clouds. The ITCZ undergoes a seasonal traverse of the Sudan: it moves northwards during the first half of the year to reach a maximum latitude on average between Atbara and Wadi Halfa during July and August, after which it retreats southwards, rather more quickly than it advanced, to reach the extreme south of the country in December and January. On only a few days each year is the ITCZ found to the north of Wadi Halfa.

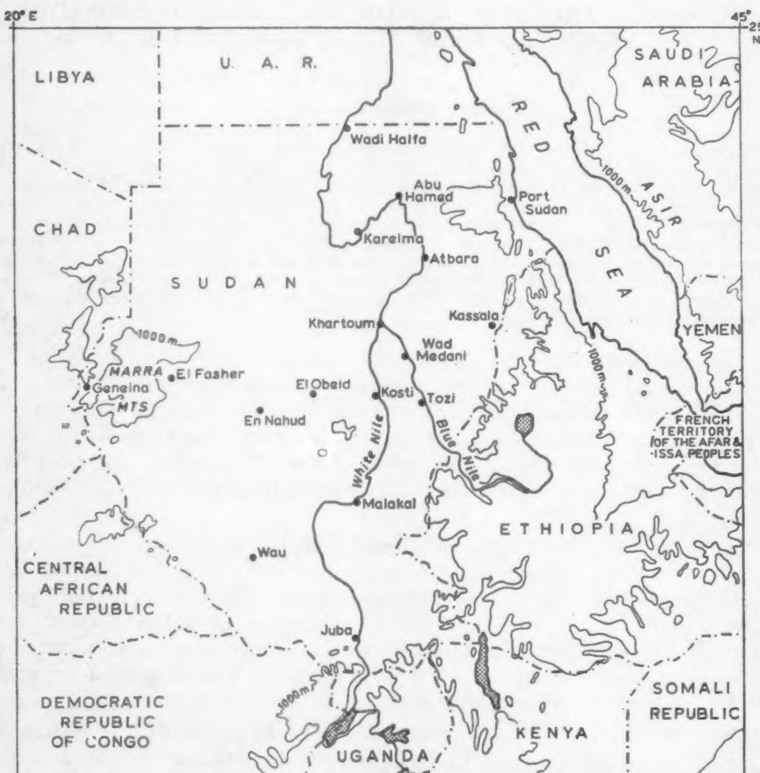

FIGURE 1—MAP OF THE SUDAN SHOWING PLACES MENTIONED IN THE TEXT

Data. As part of a larger study of the ITCZ over the Sudan, an analysis has been made of the diurnal incidence of rainfall at 17 synoptic reporting stations, based on autographic rain-gauge data tabulated by the Sudan Meteorological Service. These tabulations listed, for each hour of the day, the number of occurrences of rainfall in each month, over a period of 15 years

at most places. To reduce irregularities in the diurnal patterns resulting from the use of such a short period of observations, particularly for the northern stations with infrequent falls, the data were combined into three-hourly periods. Table I presents them in this form. These periods are referred to in the following discussion in general terms, and all times are local (GMT plus two hours) :

00–03 h = night	12–15 h = early afternoon
03–06 h = early hours	15–18 h = late afternoon
06–09 h = early morning	18–21 h = early evening
09–12 h = late morning	21–24 h = late evening

For each three-hourly period the combined number of hours with rain is made up from data for the three constituent one-hourly periods and expressed in Table I as a percentage of a total number of hours with rain in all 24 one-hour periods. For example, during July at Khartoum, of the 475 hourly periods with rain, 18 per cent were between 00 and 03 h. In this instance, there were 40 occasions for the period 00–01 h, 31 for 01–02 h, and 17 for 02–03 h. The total, 88, is 18·7 per cent of the 475 hourly periods. Expressing all eight entries to the nearest one per cent, smoothing reduces this to 18 per cent. Only months with rainfalls exceeding 0·1 inch (2·5 mm) have been tabulated, except for Wadi Halfa where, because falls are so small, July and August occurrences have been combined.

Analysis. It is convenient to consider first the diurnal incidence of rainfall during July, at the height of the monsoon; August shows closely similar features. Although the diurnal patterns vary with location (Figure 2), the stations may be grouped under four types with the following characteristics:

(i) Well-defined maximum in the afternoon or early evening, and infrequent rains from late evening to dawn. There is often evidence for a feeble secondary maximum during the early morning. Wadi Halfa, Kareima, Abu Hamed, En Nahud, Wau and Port Sudan.

(ii) Rainfall well distributed throughout the day. There is a maximum, usually weak, in the *afternoon* or *evening*, and there is often also a feeble secondary maximum during the early morning. Atbara, Kassala, El Obeid, Malakal, Juba, El Fasher and Geneina.

(iii) Rainfall well distributed throughout the day. There is a maximum, usually weak, in the *morning*. Kosti and Tozi.

(iv) Well-defined maximum between late evening and the early hours with infrequent rains during the middle of the day. Wad Medani and Khartoum.

From Figure 2 it can be seen that the distribution of these four types of stations forms a definite pattern over the Sudan. Type (i) is to be found in the middle of the country, between the extensive highland massif of Ethiopia and the smaller Marra Mountains. Except for El Fasher and Geneina, the remaining stations of types (ii) to (iv) lie within about 700 km of the Ethiopian highlands. There is a progression northwards from type (ii) to type (iv); Kassala is the only exception.

Concerning the changes in the diurnal patterns through the rainy season, the stations can be reclassified as follows, using the same headings but

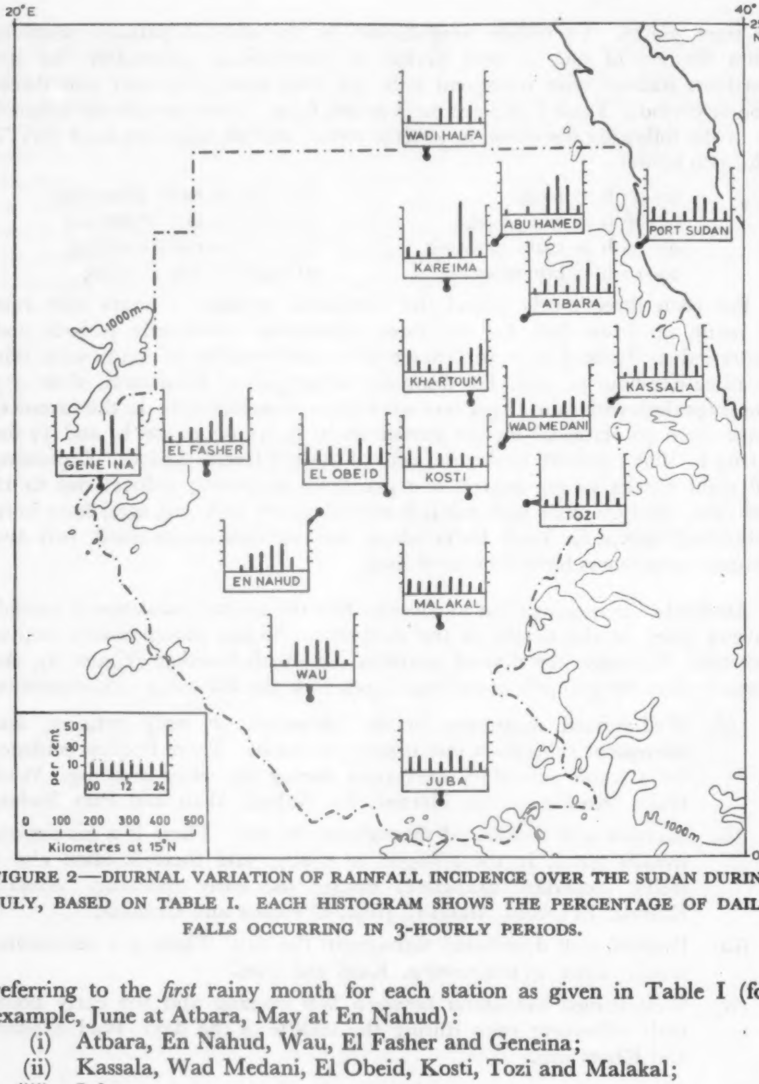

FIGURE 2—DIURNAL VARIATION OF RAINFALL INCIDENCE OVER THE SUDAN DURING JULY, BASED ON TABLE I. EACH HISTOGRAM SHOWS THE PERCENTAGE OF DAILY FALLS OCCURRING IN 3-HOURLY PERIODS.

referring to the *first* rainy month for each station as given in Table I (for example, June at Atbara, May at En Nahud):

(i) Atbara, En Nahud, Wau, El Fasher and Geneina;
(ii) Kassala, Wad Medani, El Obeid, Kosti, Tozi and Malakal;
(iii) Juba;
(iv) Khartoum.

Correspondingly, using the diurnal patterns during the *last* rainy month, the stations may be grouped:

(i) Atbara, Tozi, En Nahud, Wau, El Fasher and Geneina;
(ii) Kassala, Wad Medani, El Obeid, Kosti and Malakal;
(iii) Juba;
(iv) Khartoum.

The grouping is substantially the same at the two extremes of the rainy season.

From Table I, the following generalizations may be made. At distances greater than about 700 km from the Ethiopian highlands rain falls most frequently in the afternoon or early evening; at other times of the day it is unusual although there is a tendency towards a feeble secondary maximum in the early morning. This pattern applies throughout the rainy season. Nearer the Ethiopian highlands, falls of rain are more evenly distributed through the day although there is usually a weak maximum in the afternoon. At the height of the monsoon this maximum becomes progressively earlier in the day as Khartoum is approached from the south. Perhaps the most outstanding feature of these diurnal patterns is the persistence in all months of a maximum near or soon after midnight at Khartoum.

Discussion. Since rain clouds are formed by the ascent of moist air, it follows that the diurnal incidence of rainfall must be determined by the diurnal variations both of upcurrents and of moisture content. Some allowance must be made for the possibility of temporary storage, since clouds are observed to continue raining after the upcurrents have ceased.

Broadly speaking, upcurrents leading to rainfall may be divided into two types: those caused by mountains acting as a barrier to horizontally flowing airstreams, and those associated wtih low-level convergence of the wind field within disturbances particularly those developing in areas having horizontal temperature gradients. Over a flat country like the Sudan, barrier effects as a significant source of rainfall may be set aside. Disturbances, with low-level convergence, occur over a wide range of scales, but for convenience may be considered as either convection (small-scale, short-lived showers, or sometimes larger and longer-lived self-propagating convective storms) or synoptic-scale disturbances.

The moisture content of the air can be altered in three ways: by addition or subtraction of water vapour (evaporation or condensation), by mixing with different air (as a result of convection), and by replacement with different air (as a result of advection, both horizontal and vertical). Away from areas of falling rain, the only source of water vapour is the earth's surface. Over the Sudan, the swamps and cultivated areas along the Nile and its tributaries are local sources, together with the Red Sea, but it is likely that the majority of the vapour in the equatorial westerlies has been advected over long distances, especially from the South Atlantic Ocean. Water vapour is carried upwards both by convection and by mass-ascent within large disturbances. Horizontal advection may also be significant near the intertropical convergence zone (ITCZ), where moisture gradients are large. Thus, the moisture content is itself controlled by the windflow, including both convective and advective elements.

Synoptic disturbances. Before passing to a discussion of convection over the Sudan, it is convenient to consider first two mechanisms leading to mass-ascent, namely, travelling synoptic disturbances and the ITCZ. It is a fact that both the extent and the intensity of rainfall over the Sudan vary considerably from day to day, suggesting the existence of synoptic disturbances. Over eastern Africa, Johnson[12] has shown the existence of such disturbances but they were found not to be of the travelling type. Rain areas developed and decayed more or less *in situ,* not as a result of local instability but from

TABLE I—PERCENTAGE DISTRIBUTION OF AVERAGE DAILY RAINFALL OCCURRENCES OVER 3-HOURLY PERIODS FOR EACH MONTH OF THE MONSOON SEASON AT 17 STATIONS IN THE SUDAN

Station	Month	00 to 03	03 to 06	06 to 09	09 to 12	12 to 15	15 to 18	18 to 21	21 to 24	Total hourly obs.
WADI HALFA 21°50′N 31°18′E	July + Aug.*	7	0	0	11	29	36	14	3	28
ABU HAMED 19°32′N 33°19′E	July	3	0	7	0	23	35	25	7	31
	Aug.	2	2	2	0	23	33	29	9	45
PORT SUDAN 19°35′N 37°13′E	July	11	8	7	8	22	20	16	8	89
	Aug.	3	7	0	6	36	20	15	13	61
KHARTOUM 15°36′N 32°33′E	May	27	12	6	2	8	11	13	21	95
	June	19	15	4	2	3	16	23	18	119
	July	18	8	6	3	7	12	21	25	475
	Aug.	17	19	12	6	6	8	16	16	532
	Sept.	23	19	9	1	3	9	16	20	270
	Oct.	25	7	1	0	3	10	22	32	72
EL OBEID 13°10′N 30°14′E	May	12	6	2	0	29	25	19	7	89
	June	10	8	7	7	11	32	15	10	309
	July	12	10	13	11	11	20	11	12	669
	Aug.	12	12	14	10	16	17	9	10	885
	Sept.	8	11	12	14	18	17	12	8	419
	Oct.	7	2	5	2	21	34	19	10	149
KOSTI 13°10′N 32°40′E	May	16	9	5	5	6	20	20	9	128
	June	14	14	14	7	6	22	14	9	295
	July	14	18	19	11	11	12	9	6	854
	Aug.	14	19	19	12	9	12	9	6	860
	Sept.	11	18	15	9	10	16	14	7	365
	Oct.	8	13	7	2	9	28	25	8	143

Station	Month	00 to 03	03 to 06	06 to 09	09 to 12	12 to 15	15 to 18	18 to 21	21 to 24	Total hourly obs.
KAREIMA 18°33′N 31°51′E	July	6	4	8	0	2	53	23	4	49
	Aug.	4	5	9	4	5	36	34	3	116
ATBARA 17°42′N 33°58′E	June	2	2	0	4	18	47	25	2	45
	July	2	12	11	7	16	27	19	6	151
	Aug.	6	8	9	1	14	29	23	10	178
	Sept.	20	7	2	0	5	33	13	20	45
KASSALA 15°28′N 36°24′E	May	7	16	7	0	9	18	32	11	56
	June	2	3	1	4	6	21	47	16	107
	July	2	10	12	11	20	17	19	9	543
	Aug.	1	6	14	14	17	19	25	4	620
	Sept.	2	5	5	4	13	24	38	9	255
	Oct.	2	7	5	2	14	39	20	11	56
EN NAHUD 12°42′N 28°26′E	May	0	0	2	5	17	42	34	0	41
	June	0	2	8	7	9	44	28	2	121
	July	0	3	17	17	23	27	13	0	266
	Aug.	1	2	18	23	23	24	9	0	318
	Sept.	0	0	10	15	23	38	14	0	154
	Oct.	2	2	16	12	21	35	10	2	49
WAD MEDANI 14°42′N 33°29′E	May	6	6	3	6	10	23	31	15	95
	June	18	5	1	3	8	17	27	21	221
	July	16	16	10	4	9	13	17	15	561
	Aug.	22	17	12	4	5	11	14	15	632
	Sept.	20	17	13	2	7	18	13	10	208
	Oct.	13	8	2	0	12	21	24	20	110

* Both months combined, since falls are rare

TABLE I—PERCENTAGE DISTRIBUTION OF AVERAGE DAILY RAINFALL OCCURRENCES OVER 3-HOURLY PERIODS FOR EACH MONTH OF THE MONSOON SEASON AT 17 STATIONS IN THE SUDAN

Station	Month	00 to 03	03 to 06	06 to 09	09 to 12	12 to 15	15 to 18	18 to 21	21 to 24	Total hourly obs.
TOZI 12°44′N 34°08′E	May	6	8	13	6	18	20	23	6	96
	June	8	10	13	7	11	18	18	15	259
	July	6	9	16	19	16	13	14	7	487
	Aug.	3	7	18	14	15	16	16	11	427
	Sept.	4	8	17	14	13	20	18	6	208
	Oct.	0	1	5	13	31	33	11	6	127
EL FASHER 13°37′N 25°20′E	June	4	14	9	8	9	26	24	6	135
	July	2	9	11	11	17	27	20	3	397
	Aug.	3	13	14	10	14	24	19	3	560
	Sept.	5	13	14	6	20	22	19	1	161
	Oct.	7	17	6	0	13	34	23	0	53
MALAKAL 09°33′N 31°39′E	Mar.	6	16	18	15	17	17	10	1	96
	Apr.	8	10	12	15	26	11	10	8	273
	May	5	7	15	17	23	20	10	3	590
	June	7	8	13	16	20	18	10	8	922
	July	11	12	11	12	18	14	11	11	1330
	Aug.	11	12	10	10	15	17	13	12	1386
	Sept.	9	8	10	11	18	18	16	10	906
	Oct.	7	7	7	9	21	21	17	11	558
	Nov.	4	11	20	15	31	13	4	2	46
JUBA 04°52′N 31°36′E	Jan.	5	3	28	12	14	11	14	13	64
	Feb.	7	8	21	18	18	11	12	5	122
	Mar.	6	11	21	17	12	10	13	10	402
	Apr.	7	8	15	18	13	15	14	10	630
	May	10	8	9	13	16	12	15	17	657
	June	12	14	16	12	17	12	9	8	529
	July	13	15	13	8	19	14	10	8	721
	Aug.	10	17	17	12	15	14	9	6	729
	Sept.	15	15	13	9	13	15	9	11	600
	Oct.	15	17	14	10	12	10	10	12	658
	Nov.	8	5	9	13	24	18	12	11	404
	Dec.	12	9	19	9	16	13	11	11	121

Station	Month	00 to 03	03 to 06	06 to 09	09 to 12	12 to 15	15 to 18	18 to 21	21 to 24	Total hourly obs.
GENEINA 13°29′N 22°27′E	May	1	2	3	5	15	55	17	2	123
	June	1	5	2	2	10	51	27	2	232
	July	2	8	9	6	17	36	19	3	652
	Aug.	2	9	11	12	17	32	14	3	920
	Sept.	3	6	9	3	14	46	16	3	361
	Oct.	5	11	8	0	8	50	18	0	64
WAU 07°42′N 28°01′E	Mar.	0	2	7	11	30	33	17	0	121
	Apr.	1	2	10	10	30	32	14	1	307
	May	0	2	9	11	21	36	20	1	420
	June	1	4	14	14	20	28	17	2	493
	July	1	3	21	17	21	22	13	2	611
	Aug.	1	3	17	17	20	25	16	1	740
	Sept.	1	1	8	9	28	35	17	1	542
	Oct.	1	0	5	8	36	35	14	1	448
	Nov.	0	2	9	2	45	33	9	0	64

For most stations data refer to the 15-year period 1951 to 1965.
Exceptions are :

Wadi Halfa, 1951 to 1964 (14 years)
Khartoum, 1951 to 1966 (16 years)
Wad Medani, 1957 to 1966 (10 years)
Tozi, 1957 to 1965 (9 years)

dynamical causes, discussed by Johnson and Mörth,[13] and by Mörth.[14] There has not been a comparable study of such disturbances over the Sudan, but something of their nature can be deduced from the data of Table I. Thus, since travelling synoptic-scale disturbances are at most only modified by diurnal influences, their incidence over a particular place will not vary diurnally and rain associated with them should fall at all times of the day. However, because the presence of a disturbance influences the development of convection, the incidence of rainfall would probably not be exactly uniformly distributed throughout the day. A reasonably uniform distribution would suggest the presence, even dominance, of travelling disturbances; conversely, the absence of falls at a given place for some part of the day may be taken as indicative of the absence of these disturbances. As Figure 2 shows, it is the south-east of the Sudan that has the most even distribution of falls throughout the day, whereas both to the west and north of this area there are times when rainfall incidence falls to near zero. It is therefore reasonable to deduce that disturbances occur over the south-eastern Sudan, but they form and die *in situ*. Detection of these disturbances is difficult with the existing sparse network of stations observing upper winds. It may well be that they are of a meso-scale. In passing, it is interesting to note that there is increasing evidence[15–17] for the existence of lower tropospheric cyclonic circulations moving westwards within the equatorial westerlies of West Africa. That the strongest disturbances are found in the west suggests an eastern origin but, from the evidence presented here, they do not seem to be related to those over the south-eastern Sudan.

The intertropical convergence zone. The ITCZ over the Sudan is associated on average[18] with convergence in the low-level wind field, although this need not be true on any given occasion. This convergence will lead to some lifting but, because the atmosphere is only conditionally unstable, mass-ascent of unsaturated air will be small and the convergence is likely to be relieved by a few tall, narrow and intense upcurrents within cumulonimbus clouds — the 'hot towers' of Riehl and Malkus.[19] Relative humidity is observed to be greatest around 500 mb so that any mass-ascent is likely to produce or thicken stratiform clouds near that level. Such clouds are frequently observed over the Sudan especially around dawn.

The observed hydrolapse and associated medium clouds, suggest subsidence above 500 mb. Now, the surface position of the ITCZ lies below the right exit of the core of the strong upper tropospheric winds known as the 'tropical easterly jet', a region where dynamically induced convergence and subsidence is to be expected and which has been invoked[20] as a cause of the extreme aridity of northern Africa in summer, contrasting strongly with similar latitudes over southern Asia. Tops of the stratiform medium clouds can be expected to lie, on average, near the base of the subsiding air, at a level also controlled by low-level convergence and ascent associated with the ITCZ. Thus, the altitude of the cloud tops should undergo changes accompanying diurnal variations of the low-level convergence. Now, both the westerlies and the trades over the Sudan show a diurnal variation of speed. Above the friction layer, they accelerate at night to reach a maximum around dawn at about 500 m above the ground; such maxima have been known for some time.[21–23] The resulting maximum convergence around dawn is

consistent both with an observed decrease in amounts of medium cloud during the morning, and the widely occurring tendency for rainfall incidence to increase in the early hours and early morning, sometimes leading to a weak secondary maximum (Figure 2). Synoptic reports around dawn show a predominance of light rainfall, sometimes continuous, in contrast to afternoon and evening showers and thunderstorms.

Concerning the origin of the night-time acceleration, studies in the U.S.A.[24–28] have shown that, as a result of the rapid removal around dusk of drag associated with small-scale convective turbulence, winds at the top of the evening boundary layer accelerate from their previously sub-geostrophic speeds. Inertial oscillations can develop leading, on occasions, to considerably super-geostrophic speeds later in the night.[29–31] Such accelerations have been particularly noticeable[32,33] with southerly streams possessing reversed shear, i.e. with warmest air to the left. Over the Sudan, the equatorial westerlies, deflected to south-westerlies by the Ethiopian highlands, have similar properties, with the axis of highest temperatures lying near the ITCZ, and a similar inertial oscillation is probably responsible, at least in part, for the observed diurnal changes of wind speed there in the lower troposphere.

Differential heating of the Nile plains and Ethiopian highlands. Bleeker and Andre[34] have suggested that broad-scale motions can be set up as a result of differential heating of air over a plain compared with the slopes of a neighbouring mountain mass. Over the central plains of the U.S.A. in summer, they found that diurnal variation in convergence of the wind fields in the lower and middle troposphere supported the suggestion. It is perhaps significant that the horizontal dimension of the circulation envisaged by Bleeker and Andre, between the Rockies and the central plains, is comparable to the distance between the Ethiopian plateau and the western part of the plains in the Nile basin. Suppression of afternoon cumulus development has certainly been observed elsewhere over low ground adjacent to mountains, although admittedly on a smaller scale than envisaged here. Thus, Malkus[35] described a 'subsidence ring' around the mountainous island of Puerto Rico, leading to a clear strip having a width comparable to the radius of the island. Concerning the Sudan, such a mechanism would enhance the development of convective storms over the Ethiopian highlands, and to a lesser extent the Marra Mountains, but inhibit their development over the plains, the effect decreasing with increasing distance from the mountains. Figure 2 shows that the normal, sharply defined late afternoon or early evening maximum associated with convection is present at places distant from the Ethiopian highlands, such as Wadi Halfa, Kareima and Abu Hamed, whereas at En Nahud and Wau the afternoon maxima are distinctly flat when one might expect a progressive increase in rainfall incidence from the time of onset to a maximum in the late afternoon or early evening. The flatness of the maximum could be attributed to a reduction of convective activity as a result of reduced insolation following the accumulation of persistent tops of cumulus clouds spreading in mid-troposphere. However, the coverage of medium-level clouds is observed to decrease from morning to afternoon. A likely cause of the flattening is a decrease in the lapse rate or, more especially, in the humidity of the environment during the afternoon as a result of weak subsidence.

Closer to the highlands, the influence on afternoon convection of subsidence, resulting from differential heating of mountains and plains, should be expected to increase. Type (ii) stations certainly show only weak afternoon maxima during the middle of the rainy season, and this subsidence hypothesis is supported by the tendency for these stations to show a type (i) diurnal pattern at the extremes of the season, when an afternoon or evening maximum becomes more pronounced. However, such a maximum could well be a result of a decrease in either effectiveness or incidence of disturbances able to yield rain at other times of the day, caused perhaps by the disturbances being nearer to the surface position of the ITCZ, where humidities are lower, on average, than further south.

Some of the type (ii) stations show a feeble secondary maximum in the early morning, but type (iii) stations have their greatest maxima in the mornings during the rainiest months. At Tozi this maximum is in the late morning; perhaps this is a result of extreme suppression of afternoon convection. However, at the limits of the rainy season, the late afternoon or early evening maximum returns strongly. If this reflects a weakening of the differential heating circulation in those extreme months, it is likely that latent heat, released within storms developing over the plateau during the height of the monsoon rains, adds to the energy of the circulation, since the direct daily heating of the plateau by insolation is not likely to vary significantly from May to October near 10° N as a result of either changes in elevation of the sun, or day-time cloud cover over the plateau. At Kosti, the maximum is displaced to the early morning. This may represent not only a strong suppression of afternoon convection but also an enhancement of rains around dawn, for reasons to be discussed.

Part II of this paper will be published in May.

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Summary. This paper presents the results of a test of the method due to Saunders for forecasting night minimum temperatures at screen level. The test was made at 10 stations in eastern England for the period 1961–65 using the curves and corrections devised by Tinney and Menmuir.[1] The mean error of the whole set of forecasts was −0·3 degC with a standard deviation of 1·89 degC and the sample is of sufficient size to give a good indication of the order of accuracy which can be achieved by the method.

The percentage probabilities of air frost corresponding to certain forecast screen minimum temperatures are given in Table V and the relative contributions which the errors in the method and the errors in forecasting make to the total error are discussed and summarized in Tables VI, VII and VIII.

Tinney and Menmuir[1] have described how they constructed cooling curves for use with the method due to Saunders for forecasting night minimum air

Closer to the highlands, the influence on afternoon convection of subsidence, resulting from differential heating of mountains and plains, should be expected to increase. Type (ii) stations certainly show only weak afternoon maxima during the middle of the rainy season, and this subsidence hypothesis is supported by the tendency for these stations to show a type (i) diurnal pattern at the extremes of the season, when an afternoon or evening maximum becomes more pronounced. However, such a maximum could well be a result of a decrease in either effectiveness or incidence of disturbances able to yield rain at other times of the day, caused perhaps by the disturbances being nearer to the surface position of the ITCZ, where humidities are lower, on average, than further south.

Some of the type (ii) stations show a feeble secondary maximum in the early morning, but type (iii) stations have their greatest maxima in the mornings during the rainiest months. At Tozi this maximum is in the late morning; perhaps this is a result of extreme suppression of afternoon convection. However, at the limits of the rainy season, the late afternoon or early evening maximum returns strongly. If this reflects a weakening of the differential heating circulation in those extreme months, it is likely that latent heat, released within storms developing over the plateau during the height of the monsoon rains, adds to the energy of the circulation, since the direct daily heating of the plateau by insolation is not likely to vary significantly from May to October near 10° N as a result of either changes in elevation of the sun, or day-time cloud cover over the plateau. At Kosti, the maximum is displaced to the early morning. This may represent not only a strong suppression of afternoon convection but also an enhancement of rains around dawn, for reasons to be discussed.

Part II of this paper will be published in May.

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Summary. This paper presents the results of a test of the method due to Saunders for forecasting night minimum temperatures at screen level. The test was made at 10 stations in eastern England for the period 1961–65 using the curves and corrections devised by Tinney and Menmuir.[1] The mean error of the whole set of forecasts was −0·3 degC with a standard deviation of 1·89 degC and the sample is of sufficient size to give a good indication of the order of accuracy which can be achieved by the method.

The percentage probabilities of air frost corresponding to certain forecast screen minimum temperatures are given in Table V and the relative contributions which the errors in the method and the errors in forecasting make to the total error are discussed and summarized in Tables VI, VII and VIII.

Tinney and Menmuir[1] have described how they constructed cooling curves for use with the method due to Saunders for forecasting night minimum air

temperatures for 13 stations in eastern England. The curves were based on about 14 000 observations made during the four years from October 1961 to September 1965 inclusive. For each station they devised two sets of curves: one for the summer from April to September, and the other for winter from October to March. The curves were worked out for clear nights and Tinney and Menmuir presented corrections to be made for other cloud amounts.

The present note reports the results of a test of accuracy based on independent data for the 12 months from April 1967 to March 1968 inclusive. For various reasons only 10 of the original 13 stations were able to participate in the test; their names are given in Tables I and II. The nomogram curves are constructed for clear nights and the corrections for various cloud amounts are linear, at least within the tolerances to which forecasters work. Thus for the purpose of the test it was sufficient that forecasts of night minimum temperatures (to the nearest 0·1 degC) were made for two classes of nights :

(i) Clear nights — those when it was forecast that the average cloud cover would be 2/8 or less (excluding cirrus).

(ii) Cloudy nights — those when it was forecast that the average cloud cover would be 6/8–8/8 (excluding cirrus).

TABLE I—SUMMARY OF RESULTS OF A TEST OF FORECASTING NIGHT MINIMUM TEMPERATURES BY THE METHOD DUE TO SAUNDERS, PERIOD APRIL – SEPTEMBER 1967

Station	Clear nights: Number of occasions	Clear nights: Mean error*	Clear nights: Root-mean-square error	Clear nights: σ	Cloudy nights: Number of occasions	Cloudy nights: Mean error*	Cloudy nights: Root-mean-square error	Cloudy nights: σ
		degrees Celsius				*degrees Celsius*		
Wyton	39	−0.30	1.78	1.75	58	−0.97	2.49	2.29
Waddington	21	−0.96	1.82	1.55	87	+0.31	1.99	1.73
Finningley	26	+0.55	1.82	1.73	39	−0.48	1.29	1.20
Marham	22	−1.93	2.48	1.56	37	−0.18	2.14	2.13
Mildenhall	61	−0.83	2.36	2.21	64	−0.17	2.13	2.12
Wittering	45	−0.77	2.44	2.31	20	+0.37	1.37	1.31
Cottesmore	9	+0.80	1.27	0.99	41	+0.22	1.63	1.61
Bassingbourn	27	−0.94	1.87	1.61	36	−0.77	1.92	1.76
Lindholme	27	−0.14	1.33	1.32	43	−0.75	1.80	1.63
Scampton	37	+0.76	1.49	1.24	46	−0.09	1.47	1.44
Totals and weighted means	314	−0.44		1.81	471	−0.23		1.81

Total number of occasions = 785. Mean value of σ for clear and cloudy nights = 1.81 degC.
*Error = forecast minimum temperature − actual minimum temperature.

TABLE II—SUMMARY OF RESULTS OF A TEST OF FORECASTING NIGHT MINIMUM TEMPERATURES BY THE METHOD DUE TO SAUNDERS, PERIOD OCTOBER 1967 – MARCH 1968

Station	Clear nights: Number of occasions	Clear nights: Mean error*	Clear nights: Root-mean-square error	Clear nights: σ	Cloudy nights: Number of occasions	Cloudy nights: Mean error*	Cloudy nights: Root-mean-square error	Cloudy nights: σ
		degrees Celsius				*degrees Celsius*		
Wyton	48	−2.00	3.37	2.71	51	−0.25	2.85	2.84
Waddington	36	−0.51	1.53	1.44	51	−0.04	1.92	1.92
Finningley	22	+0.15	1.17	1.16	34	−0.17	1.71	1.70
Marham	13	−0.08	3.32	3.32	28	+0.05	1.96	1.96
Mildenhall	42	−0.92	2.00	1.78	48	−0.76	2.25	2.12
Wittering	8	+0.77	1.74	1.56	35	+0.57	1.81	1.72
Cottesmore	12	−0.05	1.15	1.15	34	−0.13	1.13	1.23
Bassingbourn	16	−1.01	3.07	2.90	34	−0.08	1.75	1.75
Lindholme	17	−0.44	1.23	1.15	38	−0.10	1.48	1.48
Scampton	18	+0.42	2.03	1.99	57	+0.13	1.89	1.89
Totals and weighted means	232	−0.70		2.07	410	−0.10		1.95

Total number of occasions = 642. Mean value of σ for clear and cloudy nights = 1.99 degC.
*Error = forecast minimum temperature − actual minimum temperature.

Nights when precipitation was forecast were excluded and of course forecasts could be done only when forecasters were on duty.

Let B be the forecast minimum temperature, and A the observed minimum temperature, then the error $d = B - A$.

There is a preponderance of negative mean errors in both Tables I and II for both clear and cloudy nights, but this does not necessarily mean that the curves are biased. It may simply mean that a period of 12 months is hardly long enough to eliminate bias from the means; but the test was limited to 12 months for administrative and not for scientific reasons.

If n is the number of occasions in a sample, the root-mean-square error is given by

$$s = \sqrt{\frac{\Sigma\ (B-A)^2}{n}}\ .$$

Because the mean of the errors is not zero, s is not the same as the standard deviation σ in which the deviations are measured from the mean; but σ for the sample may be calculated from the formula

$$\sigma^2 = s^2 - d_m^2$$

where

$$d_m = (1/n)\ \Sigma\ (B - A).$$

The root-mean-square errors and standard deviations calculated in this way for individual stations for the summer six months and for the winter six months are shown in Tables I and II. While there are some fairly large differences in individual cases, these tables taken as a whole indicate that, on average, for all 10 stations over a whole year, the accuracy obtained in winter by means of the winter curves is of the same order as that obtained in summer with the summer curves; similarly the cloud correction used on cloudy nights produces results of the same order as those obtained on clear nights.

The errors in the forecasts consist of two parts: the errors due to the curves and the appropriate corrections and those due to forecasting wind, dew-point and cloud amount. The mean error due to the curves should be zero because of the way in which the curves were constructed — this will be examined more fully later. On the other hand, the mean forecasting error may or may not be zero. In fact the mean error of the sample is −0·3 degC; this is not large. Moreover, there is not much difference between the root-mean-square error and the standard deviation except in two or three instances. But as the mean of the sample is the best estimate of the mean of the population, it is appropriate to study the standard deviation σ rather than the root-mean-square error. Table III summarizes the values of the mean error and the standard deviation for all stations for the whole 12 months; σ works out as 1·89 degC.

TABLE III—SUMMARY OF FORECASTS FOR ALL STATIONS FOR THE WHOLE YEAR

	Number of forecasts	Mean error	σ
		degrees Celsius	
Clear nights	546	−0·55	1·93
Cloudy nights	881	−0·17	1·88
Clear and cloudy nights	1427	−0·31	1·89

Table IV shows the actual percentages of the forecasts which were within specified limits. For comparison it also shows corresponding percentages in a normal distribution with a standard deviation of 1·89 degC and a mean error of − 0·3 degC. (The forecasts were actually made to a tenth of a degree, but Table IV has been compiled in half degrees to keep the table short.) The agreement between the two columns of figures is evidence that the distribution of errors in the forecasts approximates closely to a normal distribution.

TABLE IV—PERCENTAGE OF FORECASTS FALLING WITHIN SPECIFIED LIMITS

Limits (degC)	± 0·5	± 1·0	± 2·0	± 3·0	± 4·0
Actual percentage	26	42	71	89	95
Percentage for a normal distribution	21	40	70	88	96

Note: The figures on the line labelled 'Actual percentage' relate to the actual forecasts made during the period from April 1967 to March 1968. The figures on the last line are those which relate to a normal distribution with a mean of − 0·3 degC and a standard deviation of 1·89 degC.

Probability of occurrence of an air frost. Because forecasts are often not wholly exact, it is possible for a frost to occur with a forecast above 0°C and it is also possible for no frost to occur with a forecast below 0°C. It would therefore be useful for forecasters to know the statistical probability of an air frost occurring with any particular forecast screen minimum temperature.

The distribution of forecast errors is illustrated in Figure 1, which represents a normal distribution of 1427 errors with mean − 0·3 degC and standard deviation 1·89 degC as in the sample for 1967–68. Let the forecast night minimum temperature be +2°C. If this forecast is more than 2 degC too warm an air frost will occur. The probability of an air frost is therefore the same as the probability of an error more than 2 degC too warm. This

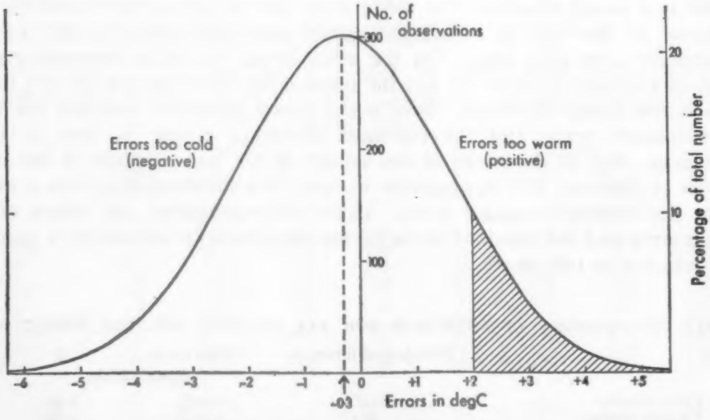

FIGURE 1—A NORMAL DISTRIBUTION CURVE OF FORECAST ERRORS

probability is the ratio of the shaded area in Figure 1 to the total area under the curve. To find the probability, a table of areas under the standardized normal curve[2] is used; under this curve the total area is unity, which corresponds to the maximum possible probability, and the mean is zero. Before the tables are used, the variable x must be standardized by subtracting the mean (−0·3 degC) and dividing by the standard deviation (1·89 degC), i.e. the mean of the distribution must be shifted to zero and deviations from it measured in terms of standard deviations; for example, if $x = +2$ degC, the mean $= -0{\cdot}3$ degC and the standard deviation $\sigma = 1{\cdot}89$ degC, then the standardized normal variable z is given by

$$z = \frac{+2-(-0{\cdot}3)}{1{\cdot}89}\,\sigma = 1{\cdot}22\,\sigma.$$

From the tables the tail area to the right of $z = 1{\cdot}22\sigma$ is 0·11 of the total area under the curve and this is the probability of an error more than 2 degC too warm. It is also the probability of an air frost when the forecast night minimum is +2°C. Table V gives the percentage probabilities of an air frost for various forecast night minimum temperatures. Rounded off to some convenient percentage (say 10 per cent or 20 per cent) these figures based on the 1967–68 data provide forecasters with an indication of the frequency with which they may expect an air frost to occur with any particular forecast of screen minimum temperature.

TABLE V—PERCENTAGE PROBABILITY OF AN AIR FROST CORRESPONDING TO CERTAIN FORECAST SCREEN-MINIMUM TEMPERATURES

Forecast night minimum temperature(°C)	+4	+3	+2	+1	0	−1	−2	−3	−4	−5
Percentage probability of an air frost	1	4	11	25	49	64	82	92	97	99

Note: The probabilities are calculated for a normal distribution with a mean of −0·3 degC and a standard deviation of 1·89 degC, as found in the 1967–68 data analysed.

Sources of error. As stated before, the error in a forecast consists of two parts: the error due to the curves with the appropriate corrections, and the error due to forecasting mean wind speed, dew-point and cloud amount for the night. These two errors may be disentangled if the forecaster does his calculations again after the event using the actual conditions for the night as recorded in the *Daily Register*. Five stations did this and the results were called aftercasts.

Because of the instructions given to the forecasters at the beginning of the investigation, the aftercasts relate only to those nights when the cloud was forecast to be 0–2/8 or 6/8–8/8. If subsequent events showed that the actual mean cloud amount was in the range of 3/8–5/8, the aftercast was made using the appropriate correction recommended by Tinney and Menmuir.[1]

Let σ_n be the standard deviation of the errors inherent in the method, i.e. in the curves and the corrections

and σf the standard deviation of the errors made by the forecaster in forecasting conditions for the night.

These are related by the equation[3]

$$(\sigma f)^2 = \sigma^2 - \sigma_n{}^2.$$

Values of each of these quantities are listed by season in Tables VI and VII and summarized in Table VIII.

TABLE VI—ANALYSIS OF SOURCES OF ERRORS: SUMMER 1967

Station	Aftercast data using nights forecast as clear					Aftercast data using nights forecast as cloudy				
	No. of occasions	E_n	σ	σ_n	σ_f	No. of occasions	E_n	σ	σ_n	σ_f
Finningley	31	+0·20	1·73	1·31	1·13	50	+0·27	1·20	0·83	0·87
Marham	21	−1·05	1·56	1·40	0·68	38	−0·83	2·13	1·62	1·39
Mildenhall	54	−0·55	2·21	1·34	1·76	62	−0·02	2·12	1·64	1·35
Wittering	24	+0·14	2·31	0·84	2·15	39	+0·34	1·31	1·11	0·69
Bassingbourn	21	−0·30	1·61	0·85	1·38	42	−0·50	1·76	1·09	1·29

TABLE VII—ANALYSIS OF SOURCES OF ERRORS: WINTER 1967–68

Station	Aftercast data using nights forecast as clear					Aftercast data using nights forecast as cloudy				
	No. of occasions	E_n	σ	σ_n	σ_f	No. of occasions	E_n	σ	σ_n	σ_f
Finningley	21	+0·50	1·16	0·88	0·76	34	+0·09	1·70	1·01	1·37
Marham	15	+0·97	3.32	1·69	2·86	26	−0·97	1·96	0·76	1·84
Mildenhall	35	−0·67	1·78	1·67	0·60	52	−0·07	2·12	1·83	1·02
Wittering	8	−0·47	1·56	1·47	0·53	35	+0·16	1·72	1·09	1·33
Bassingbourn	22	−0·17	2·90	1·26	2·61	28	−0·49	1.75	0·92	1·49

TABLE VIII—SUMMARY OF WEIGHTED MEANS FOR ALL FIVE STATIONS COLLECTIVELY

Period	Type of night	No. of occasions	E_n	σ	σ_n	σ_f
Summer 1967	Forecast as clear	151	−0·32	1·81	1·11	1·46
	Forecast as cloudy	231	−0·12	1·91	1·42	1·26
	All nights forecast	382	−0·20	1·87	1·29	1·36
Winter 1967–68	Forecast as clear	101	−0·06	2·13	1·74	1·56
	Forecast as cloudy	175	−0·19	1·87	1·25	1·40
	All nights forecast	276	−0·14	1·97	1·44	1·46
Whole year 1967–68	Forecast as clear	252	−0·22	1·93	1·37	1·49
	Forecast as cloudy	406	−0·15	1·89	1·34	1·33
	All nights forecast	668	−0·17	1·91	1·35	1·40
Winter 1963–64	All nights	350	0		1·56	

Notation for Tables VI, VII and VIII

- E_n is the mean error due to the curves and corrections.
- σ is the total standard deviation of the sample.
- σ_n is the standard deviation of the errors due to the curves and corrections.
- σ_f is the standard deviation of the errors made by the forecaster in forecasting conditions for the night.

The investigation started with forecasts of clear and cloudy nights but, as stated above, some occasions of 3/8–5/8 cloud were included in the aftercasts, and it must be asked whether this invalidates the results. Gordon and Virgo[4] reported a similar investigation for the winter of 1963–64 with no distinction between cloud amounts. Their results for the five stations concerned in the present investigation were compared by means of students' *t*-test with those in Table VII. As the difference was not significant at the 5 per cent level, the results in both investigations can be regarded as samples of the same population, and actual cloud amount therefore makes no significant difference to the minimum temperatures derived from the curves and corrections devised by Tinney and Menmuir.[1] Moreover, the *t*-test showed that the difference between the summer and winter figures in Tables VI and

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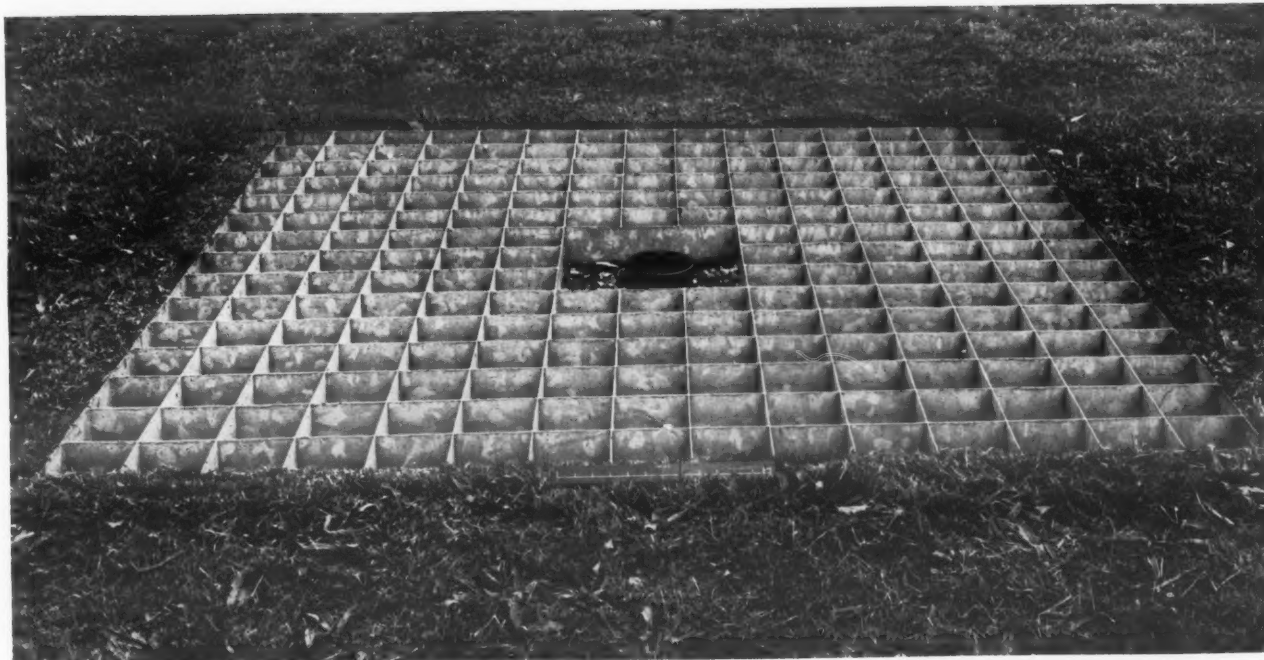

Photograph by courtesy of the Institute of Hydrology

PLATE I—GROUND-LEVEL RAIN-GAUGE WITH GRID

See page 114

PLATE II—METEOROLOGICAL OFFICE
RAIN-GAUGE MK 2

Photographs by courtesy of the Institute of Hydrology

PLATE III—METEOROLOGICAL OFFICE
RAIN-GAUGE MK 3

See page 115

PLATE IV—METEOROLOGICAL OFFICE RAIN-GAUGE MK 4

Photographs by courtesy of the Institute of Hydrology

PLATE V—FUNNEL GAUGE

See page 115

PLATE VI—SMOKE TRAJECTORY OVER MK 2 GAUGE
(Wind speed in tunnel 5·5 ft/s)

Photographs by courtesy of the University of Southampton

PLATE VII—SMOKE TRAJECTORY OVER MK 3 GAUGE
(Wind speed in tunnel 7·8 ft/s)

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VII was insignificant at the 5 per cent level and this justifies considering the year as a whole in Tables III and VIII.

The mean errors due to the curves should be zero because of the way in which they were constructed. These errors are shown as E_n for clear nights in Tables VI, VII and VIII, and the error for the winter of 1963–64, though based on all nights irrespective of cloud cover, has been included in Table VIII for comparison. This last error was exactly zero, but there was a slight negative bias in the summer of 1967 and in the winter of 1967–68.

Tables VI and VII show that there are wide variations in the ratio of σ_n to σ_f for individual stations; the ratios also vary from season to season. But when all clear and cloudy nights in the year as a whole are taken together, as Table VIII shows, the errors in the method and the errors made by the forecasters contribute roughly equal parts to the total.

Gordon and Virgo[4] discussed the magnitude of errors in forecasts of night minimum temperatures by McKenzie's method arising as a result of forecasting wind, dew-point and cloud amount, and concluded that errors in forecasting low-cloud amount introduced the greatest errors into the forecasts of night minimum temperature. The present investigation into the accuracy of the method due to Saunders produced a similar result. Forecasters at four stations examined the synoptic situations on occasions when large errors occurred and found that the great majority could be attributed to errors in forecasting low-cloud amount; in particular the forecasters at Marham specified low cloud drifting in from the North Sea.

Acknowledgements. The writers acknowledge the co-operation of all who made the observations on which the curves and corrections are based and all the forecasters who participated in the test.

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RAIN, WIND AND THE AERODYNAMIC CHARACTERISTICS OF RAIN-GAUGES

By A. C. ROBINSON* and J. C. RODDA†

Summary. The airflow round four types of rain-gauge was studied in a series of wind-tunnel experiments using tuft indicators and also smoke trajectories. A transparent gauge was used in checking that there were no air currents within the gauge. Quantitative assessments of the wind fields over the gauges were obtained from measurements made by a hot-wire anemometer which could be moved in a vertical plane oriented along the direction of the wind.

After the wind-tunnel experiments the four gauges were installed beside other gauges and rainfall measurements made over a period of six months so that comparisons could be made. The largest catch was made with a ground-level gauge.

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Introduction. Standardization of particular instruments and uniformity in the method of their installation and observation are given particular attention by the meteorologist. In the case of the measurement of rainfall, the dimensions of the rain-gauge that make up the non-recording network in Britain and its method of siting have become standardized over the past 100 years. Now there are few instruments in the United Kingdom that do not have the rim at a height of 1 foot and an orifice with a diameter of 5 inches — exceptions being the recently introduced Meteorological Office gauges[1] based on an orifice area of 150 square centimetres. A note on the units used appears at the end of this article. In other countries, different standards have been adopted for height and size of gauge and there is also a considerable variety of shape and observer practice, as well as different rules of siting. Because of these contrasts, it is not always a simple task to compare rainfall records from different parts of the world and to assist this, several comparisons of various national gauges have been made.[2] In addition, an interim reference precipitation-gauge has been adopted by the World Meteorological Organization and is being tested at a number of sites.[3]

However, it does not follow that because a particular type of gauge is employed as a standard throughout a national network, the performance of that gauge will necessarily be standard from site to site. This is due to a number of factors, the most important being wind, especially its effect on drops falling towards the gauge. Wind interacts with features of the gauge surroundings and particularly with the gauge itself, to produce eddies which divert some drops from the gauge funnel. Such effects can be extremely variable from site to site, in spite of the use of subjective rules for site selection. They cause the amount caught by the conventional elevated gauge to be less than the quantity of rain reaching the ground. This fact has been established in a number of experiments carried out in different parts of the world in which standard rain-gauges have been compared with weighing lysimeters,[4] with accurate measurements of lake level,[5] and with other rain-gauges installed with their rims flush with the ground surface and surrounded by a non-splash surface.[6,7,8] Ground-level gauges (Plate I) are being employed at a number of sites in Britain and at one, a standard gauge has caught 6·6 per cent less rain over a period of five years than a ground-level gauge and considerably less during certain individual storms.[9] These differences may not be important to the meteorologist, but in hydrology this systematic error[10] in the measurement of rainfall can be highly significant. It is particularly serious where the complete water balance of a catchment is being studied, also in flood investigations and in the assessment of water resources. In this respect meteorologists and hydrologists differ in their needs for information about rainfall; where the former can be content with an index of rain, the aim of the latter should be to obtain measurements of a known accuracy. This is particularly difficult when there is no absolute standard for rainfall measurement and until such a standard becomes available, gauges that are not subject to the source of the most serious error, namely wind, must be considered to produce the most satisfactory results.

Aerodynamic studies. In view of the importance of wind in the measurement of rainfall, it is surprising that so few studies of the aerodynamic characteristics of rain-gauges have been carried out.[11,12,13] Even fewer

attempts have been made to provide an objective method for classifying rain-gauge sites to replace the somewhat arbitrary procedures in use at present.

The first of these problems has been studied in a series of wind-tunnel experiments carried out at Southampton University.[14] The gauges used were the top sections of the Meteorological Office Mk 2 gauge, the new type Meteorological Office gauges (Mk 3 and Mk 4) and a metal Funnel Gauge (Plates II–V). The Funnel Gauge consisted of the bare essentials of a gauge: a sheet-copper funnel, five inches in diameter, slant length three and a half inches feeding into a copper tube half an inch in diameter. The top sections of each of the other gauges were mounted on cylindrical sand-filled bases such that the rim of each gauge stood one foot above the false floor of the tunnel.

Preliminary experiments to examine the airflow around each gauge were conducted using indicator tufts stuck to the gauges. The results of these experiments showed that wind speeds initially between 2 and 22 ft/s in an empty wind tunnel changed when a rain-gauge was placed in the tunnel. The air speed increased as the air passed over the top of the gauge and turbulence occurred above each gauge.

Smoke was injected into the airstream and photographs were taken of the smoke trajectories over the different gauges for wind speeds between 1 and 17 ft/s at 2-ft/s intervals, some of these results being shown here (Plates VI–VII). The results of the smoke experiments showed that up to wind speeds of 5 ft/s a slight deflexion of the air occurred over the gauges and that this deflexion appeared almost the same for all gauges. At wind speeds above 5 ft/s the smoke was lifted clear of the tops of the gauges and at about 7 ft/s the trajectory flattened out and retained approximately the same lift over the gauges for wind speeds up to 17 ft/s. The results from the Funnel Gauge were an exception, as in this case complete lift occurred at a much higher wind speed (about 14 ft/s) while at the same wind speed the amount of lift appeared to be less than for the other gauges. Observation of the smoke showed that the speed of the air increased as it passed over the top of each gauge. The height of the lift of the smoke trajectory above the gauge appeared to increase with increasing diameter of gauge and with increasing sharpness of the leading edge of the gauge for equal wind speeds. The latter point was investigated by moulding plasticine into various shapes around the rims of the gauges, a smoother profile producing less lift.

A full-scale transparent model of the top of the Mk 2 gauge was made to study the effects of air movement inside the gauge. The height of the funnel within this gauge could be altered and tests were conducted with the funnel at various depths from the rim of the gauge, namely: 0 in, $1\frac{1}{2}$ in, 3 in, and $4\frac{3}{4}$ in (the normal distance). The results of tuft and smoke experiments using this gauge showed that there was little movement of the air within the gauge and that no circulating currents were set up within it that could contribute to the lift.

In order to obtain a quantitative assessment of the wind fields over the gauges, use was made of a constant-resistance hot-wire anemometer[15,16] that could be traversed in a vertical plane along the direction of the wind. The hot wire was calibrated for varying wind speeds using a pitot tube, calibrations being made at the beginning and end of each experiment because the

calibration curve changed with tunnel temperature. Hot-wire traverses were made over the centre of each gauge starting some four inches in front of the leading edge, finishing just beyond the rear of the gauge and extending six to seven inches above it.

The results of the hot-wire anemometer experiments showed that the gauges exhibited similar aerodynamic characteristics; in particular a surface of separation was set up by the leading edge of each gauge that curved backwards over it (Figure 1). Above this surface the wind speed reached a maximum while below it a turbulent zone was set up, in which the wind

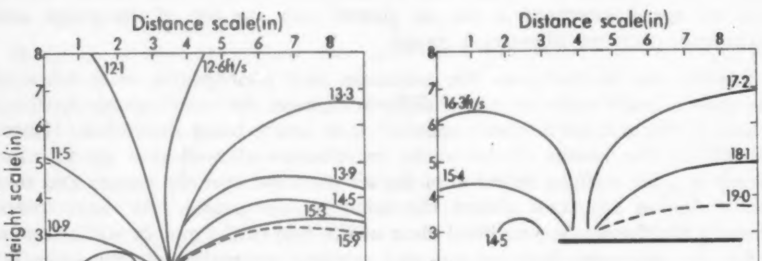

FIGURE 1—WIND-SPEED CONTOURS FOR TRAVERSES ACROSS RAIN-GAUGES

Note: The height and distance scales are referred to arbitrary zeros but the position of the gauge orifice is indicated by a thick black line on each diagram. The pecked line denotes the surface of separation. Wind speeds are indicated in ft/s and in each diagram the wind is blowing from left to right.

speed dropped considerably below the normal tunnel wind speed. The size of this zone increased with increasing wind speed, while the sharpness of the leading edge also affected its dimensions. Above the turbulent boundary, the air speed increased as it passed over the gauge, this speed depending upon the area that the gauge projected against the oncoming wind and the sharpness of the leading edge (Table I). Of the four gauges the simple cylindrical and near cylindrical shapes of the Mk 2 and Mk 3 gauges appeared to produce the least satisfactory patterns of airflow. On the other hand the more complex shapes of the Mk 4 gauge and the Funnel Gauge caused less distortion of the wind field.

TABLE I—DETAILS OF WIND-TUNNEL EXPERIMENTS

Gauge type	Speed in empty tunnel	Maximum speed above gauge	Speed increase	Max. height of turb. boundary above gauge
	ft/s	*ft/s*	*per cent*	*inches*
Mk 2	11·6	15·9	37	1·3
Mk 3	15·4	21·0	36	1·9
Mk 4	13·5	17·7	31	1·2
Funnel	14·7	19·0	29	1·2

Of course, under natural conditions, rain-gauges are subjected to a wind field which fluctuates in speed and direction and exhibits a marked profile. However, even the artificial wind-tunnel conditions must give some guide to the performance of a gauge in a real environment. In fact, when a Mk 2 gauge was placed on grass in the open and smoke was let out through the funnel, a turbulent boundary was seen and when smoke was discharged across the gauge, the flow pattern appeared similar to that existing in the tunnel.

Determination of the catch of different types of gauge. Determining the relationship between catch and the aerodynamic characteristics of a gauge is a more difficult problem than establishing the characteristics themselves. An examination of drop trajectories above the gauge by photography might provide the best solution, but there would be considerable difficulties in analysing the enormous amounts of data that would be produced. In addition, drop size would have to be measured continuously and this is not an easy task. Whether the study could be made in the open is another point that would require careful attention, because provision of the necessary facilities under cover would require an appreciable investment of capital.

An alternative, which is not entirely satisfactory, is to carry out comparative tests of the different gauges at one site. References to such comparisons abound in literature concerned with rain-gauges and usually the gauge that catches the most rain is considered the best, often without any sound reason. However, in this case, the results of the gauge comparison could be interpreted in the light of the wind-tunnel tests and from knowledge gained in previous field experiments. So following the work in the wind tunnel, the four gauges were installed alongside a number of other gauges in the site at Wallingford and compared over a period of six months. During the test it was found that the Funnel Gauge caught more rain than any other instrument except

the ground-level gauge (Table II). Of the conventional gauges, the Mk 3 caught the most and the Mk 4 the least — a somewhat surprising result in view of the slightly better performance of the latter gauge in the wind tunnel and its supposedly improved shape. Interchanging some of the gauges during the course of the experiment, confirmed that these differences in catch could not be ascribed to any consistent pattern in the distribution of rainfall across the site — a point that had been investigated in an earlier experiment. The Funnel Gauge seemed to operate best in light showers, but it caught less than the other gauges during prolonged or heavy rain, independent of wind speed. This suggests that splash-out was taking place when the surface of the funnel was wet and that under such conditions splash would be the chief source of error rather than wind. In fact, the Funnel Gauge appeared to cause a comparatively small disturbance in the wind field, so it is likely that the trajectories of drops falling over this gauge would not be greatly altered and under-registration of catch would be lessened.

TABLE II—SUMMARY OF RAIN-GAUGE RESULTS FOR WALLINGFORD

(*a*) Monthly table (period 16 Jan.–30 June 1968)

1968 Month	Mk 2	Ground-level gauge	Turf-wall gauge	Mk 3	Mk 4	Funnel Gauge
			inches			
16–31 Jan.	0·24	0·27	0·26	0·23	0·21	0·27
Feb.	0·98	1·04	1·04	0·99	0·96	0·99
Mar.	0·76	0·87	0·83	0·77	0·72	0·87
Apr.	2·06	2·20	2·14	2·13	1·95	2·09
May	2·98	3·13	3·03	3·07	2·88	3·12
June	2.29	2·41	2·37	2·32	2·22	2·37
Total	9·31	9·92	9·67	9·51	8·94	9·71

(*b*) Daily table

1968 April	Mk 2	Ground-level gauge	Turf-wall gauge	Mk 3	Mk 4	Funnel Gauge	Wind*
			inches				*mile/h*
1	0·009	0·014	0·015	0·001	—	0·004	5·5
2	0·093	0·140	0·142	0·100	0·099	0·107	3·5
3	0·009	0·011	0·011	0·009	0·008	0·011	4·0
15	0·078	0·083	0·082	0·083	0·074	0·083	3·7
16	0·249	0·274	0·258	0·257	0·227	0·238	5·1
17	0·293	0·303	0·302	0·308	0·290	0·292	2·0
18	0·269	0·273	0·265	0·265	0·242	0·257	3·4
19	0·020	0·018	0·021	0·023	0·017	0·024	1·5
21	0·003	0·007	0·004	0·003	0·001	0·007	0·5
22	0·005	0·007	0·006	0·007	0·007	0·006	0·8
23	0·071	0·074	0·072	0·075	0·066	0·078	3·3
27	0·243	0·256	0·251	0·253	0·239	0·250	3·2
28	0·229	0·240	0·235	0·244	0·218	0·232	3·3
29	0·178	0·188	0·180	0·184	0·161	0·185	2·0
30	0·313	0·311	0·299	0·316	0·305	0·313	2·0
Total	2·062	2·199	2·143	2·128	1·954	2·087	

* Average wind speed during rain.

Note: After rain the bottles containing the rain water are replaced by dry empty bottles and weight of rain is measured.

There are, of course, other ways of reducing the effect of wind such as by using a turf wall (Figure 2) or trying to eliminate it by employing a ground-level gauge. However, there may still be a slight amount of air movement

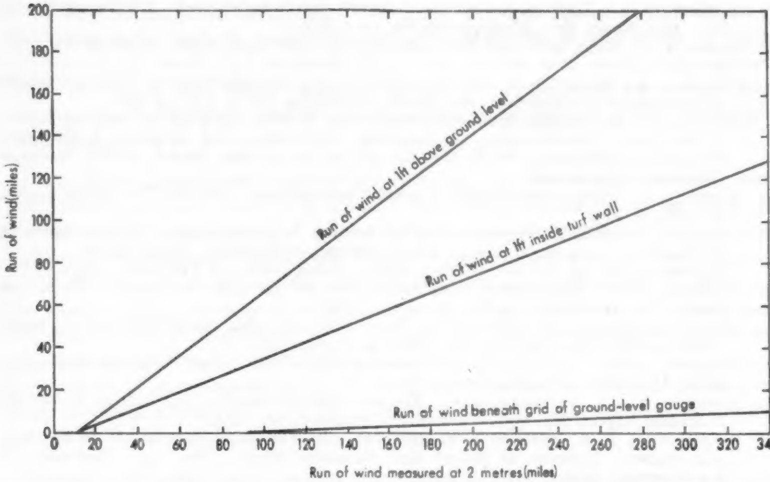

FIGURE 2—RELATIONSHIP BETWEEN RUN OF WIND AT A HEIGHT OF 2 METRES AND AT OTHER POSITIONS

about the ground-level gauge that might influence its performance. Nevertheless of the gauges tested, the ground-level gauge must be considered as producing results nearest to the true rainfall, whatever that might be for Wallingford. A system of ground-level gauges installed at representative sites throughout the country would provide a more realistic assessment of the amount and distribution of rainfall and might even allow adjustments to be made to past records.

Note on units used in this article. Measurements were made in feet per second, miles per hour, inches (rainfall and various dimensions), and miles (run of wind).

For comparison purposes the following conversion factors may be used:

1 ft/s = 0·3048 m/s	1 inch = 25·4 mm
1 mile/h = 0·447 m/s	1 mile = 1·609 km.

(Ed. note: See letter to editor on page 126.)

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THIRTEENTH RADAR METEOROLOGY CONFERENCE

By K. A. BROWNING

The Thirteenth Radar Meteorology Conference was held on 20–23 August 1968 at McGill University, Montreal. The programme was divided into sessions on radar instrumentation, measurement techniques and signal interpretation, radar climatology, severe storms, precipitation physics, mesoscale analysis, clear-air echoes, precipitation measurement, wind measurement, operational applications, and scattering and absorption. Altogether 125 papers were accepted and these were published by the American Meteorological Society in Conference Proceedings which were distributed to participants well in advance of the conference. At the conference, each author, instead of presenting his own paper, participated in an open discussion initiated by brief critical comments and questions from the session chairman. The planning of the sessions was finalized during informal workshops held at the beginning of the conference.

A feature of this conference was the increased number of contributions involving Doppler radar. Altogether there were over 20 papers involving Doppler radar, half of them being technique-oriented and half phenomenon-oriented. Doppler radar was shown to be a versatile tool in turbulence studies and for making wind measurements on the mesoscale; however, limitations in the accuracy of measuring updraught velocities in intense convective storms were recognized.

Another notable feature was the increasing interest in the application of high-power radar systems to study the structure of the clear atmosphere using refractive-index inhomogeneities as tracers. Clear-air structures observed

by radar fall into two categories: (i) clear-air convection at low levels in which the radar detects turbulent humidity gradients at the edges of rising bubbles of air, and (ii) clear-air layers at middle and upper tropospheric levels in which the radar detects refractivity turbulence associated with temperature fluctuations within turbulent layers in regions of strong vertical wind shear.

Progress in operational applications of radar, on the other hand, has been disappointingly slow in recent years. Successful identification of hail, for example, still hangs in doubt, particularly using radars at 3-cm wavelength. However, it was again emphasized that, despite limitations in the accuracy of the measurement of rainfall intensity because of uncertainties in drop-size distributions etc., there were still many areas where radar could furnish vital information unobtainable by other means. Two interesting techniques were proposed to resolve the problem of the determination of drop sizes; one of these involved the measurement of the effect of raindrop vibrations and the other involved a bistatic* approach. Unfortunately, both approaches require an accuracy of measurement not attainable at present.

During the conference, special excursions were organized to visit a new high-resolution 10-cm radar which the McGill group has installed in the Montreal area. Another high-resolution radar, which the McGill group are using in Alberta, has already yielded remarkably detailed descriptions of three-dimensional precipitation patterns within hailstorms. When related to surface hail surveys, these can be expected to provide useful constraints on the mathematical models that are now being constructed to account for the precipitation distribution in terms of realistic airflow patterns. The Alberta radar was also specially designed for polarization studies. With radars such as this we can look forward to a renewal of studies of lightning and a search for new means of hail identification.

At the end of the conference a useful summary session was held in which the session chairmen attempted to focus the discussion on the conference highlights. Prof. Hosler, in discussion of the application of radar to mesoscale studies, made the point that the prediction or control of weather on the scale which affects most people depends upon thorough observation and comprehension of mesoscale circulations. He went on to say that while obvious progress was being made by using radar techniques to define mesosystems, progress would be greater if more of the observational systems were brought to bear upon the same cloud system in a co-ordinated way. It is with this in mind that the present writer hopes that integrated studies involving radar and other techniques will find their way into phenomenonoriented conferences dealing with such topics as, for example, cloud physics.

* A bistatic radar is one in which the transmitting and receiving antennae are separated by a considerable distance.

REVIEWS

A note on climatological normals, WMO Technical Note No. 84. 275 mm × 215 mm, pp. x+19, Secretariat of the World Meteorological Organization, Geneva, 1967. Price: Sw. F. 4.

This note discusses the problem of fixing the optimum length of record for stable meteorological statistics and the means of overcoming difficulties arising from a dearth of records, the heterogeneity of the data, the variability of climatic elements and above all, the nature and extent of climatic fluctuations.

The main text is divided into 11 sections which vary in length from about half a page to two pages. These sections are as follows: (1) Introduction, (2) The presentation of climatological data, (3) The nature of climatological time series, (4) The stability of normals, (5) 'Standard length of record' and 'reference period', (6) The reference period *vis-a-vis* the purpose of normals, (7) The influence of climatic fluctuations on reference period, (8) Review of results (for temperature, atmospheric pressure, precipitation, humidity, wind and radiation), (9) Short-period averages and 'adjusted normals', (10) Statistical parameters to be mapped in climatic atlases (means, standard deviations, extremes and values for various probability levels of occurrence) and (11) Concluding remarks (which form a useful summary of the rules recommended for practice).

The main text is preceded by a brief summary, and section (8) of the text contains a small but useful table listing the approximate lengths of period (in years) needed to obtain stable frequency distributions for temperature, humidity, cloud, visibility and precipitation, for various topographical conditions (island, shore, plain, mountain) and for two broad latitudinal belts, namely extra-tropical and tropical. For many practical purposes however, longer periods may be desirable, for example, a five-year period for visibility in the London area would not be sufficient, in view of the recently recorded ten-year cycles of atmospheric pollution. Indeed, near a large (constant) urban source, the period necessary for visibility statistics can hardly be less than that for wind.

The presentation is not over-mathematical and the style is clear though considerably 'condensed'.

The note is especially valuable to meteorologists, particularly practising meteorologists, also to students and teachers of meteorology or geography from the senior-school stage upwards. For more advanced study, the list of over 30 references is far from comprehensive, omitting for example, a notable contribution[1] from a one-time member of the responsible working group of the WMO Commission for Climatology, in which the author concludes, that in view of the change in climate taking place over the greater part of the globe, a 30-year period is scientifically unjustified.

E. N. LAWRENCE

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The encyclopedia of atmospheric sciences and astrogeology, by Rhodes W. Fairbridge. 260 mm × 185 mm, pp. xv + 1200, *illus.*, Reinhold Publishing Corporation, New York, 1968. Price: £16 6*s*. 6*d*.

This encyclopedia is one of Reinhold's *One-volume encyclopedias* and is in fact Vol. II of the *Encyclopedia of earth science series*, the first volume being devoted to oceanography. As the title indicates the text is concerned both with the atmospheric sciences, mainly meteorology, and with astrogeology, a term which has not yet reached the dictionaries and is meant to include those parts of knowledge which are in the borderland of astronomy and geology, such as the properties of the earth, its near neighbours and other celestial bodies. A precise definition is given under the corresponding entry in the encyclopedia itself.

We examine an encyclopedia such as this in a different way from that in which we examine a text which has a unity of purpose, thought and writing; such unity cannot be easily attained in a large number of articles which are written by many different people and are juxtaposed by an arbitrary alphabetic convention. Perhaps above all we prize in such a book authority, vigour, clarity and uniformity, and many of the foibles which pass unnoticed or uncommented on in a text by a single author become painfully apparent in an encyclopedia in which adjacent articles are necessarily of different style and standard. It is clearly impractical to read the whole text or even all of the articles on meteorology, and one must therefore base a judgement of the whole on a selection, a procedure in criticism which must infuriate those whose articles are not read but who must yet share any general shafts of disapprobation.

There are about 300 entries in the text, ranging from comparatively short items of about 100 words to substantial essays of thousands of words, and liberal illustrations and tables are found throughout. There is a lot of good, sound meteorology to be found in these articles; the list of contributors ensures this and indeed bad meteorology could scarcely escape the eyes of critics so vigilant as Professor Fairbridge and his editorial team. On the whole the choice of material has been well conceived; if dynamical meteorologists think that there is a weighting towards static meteorology, i.e. climatology, maps of mean conditions, statistics, etc., they will reflect that this is inevitable in an encyclopedia if not in a textbook because the former must contain a lot of factual knowledge. About 4000 entries are listed in the index; presumably about half are meteorological so that clearly anyone in search of information is likely to find what he wants or a reference which will help him to find it elsewhere. No one could be seriously misled by anything that I have read.

There are, unfortunately, signs of hasty writing and a lack of editorial uniformity which occasionally blur the authority, vigour and clarity that we expect. The preface states that every article has been read by a competent critic, but we all use slipshod expressions in our speech which we do not use in writing, and too many of these loose expressions have escaped the critic's net. For example, what are we to understand on p. 136 from the following, 'In earth science it is usual to employ rectangular co-ordinates x, y, z with x as the east–west direction . . . . . y north–south . . . . .'? This is the complete

antithesis of the usual meteorological co-ordinate system and does not appear to be used elsewhere in the book. Does the following from p. 1147 make sense? 'The geostrophic wind may be considered the top (non-frictional) level of the Ekman spiral.' Again, is it true as stated on p. 1107 that 'modern numerical weather prediction is largely based on conservation of absolute vorticity, referred to the absolute (non-rotating) frame'?

The symbolism is not always uniform throughout the volume; for example the Greek 'nu' and two types of 'vee' are used for the velocity in the y-direction, and μ, m, M are used in the equation of state (under Equation of State, Lapse Rate and Density). The tables are usually well set out but one or two appear without any mention in the text, and occasionally the reader is left to guess at the units; on p. 446 one supposes that vapour pressure means saturated vapour pressure, that it is given in inches of mercury and that at 30°F, 25°F, etc. it is referred to ice. These particular tables do not agree with the *Smithsonian Tables* and their original source is not given. The units used throughout the book have not been standardized and perhaps it is a little surprising to find absolute humidity in grains per cubic foot.

It is a matter of opinion as to whether it is wise to include in one volume entries for subjects which appear to be quite disparate. One could argue a good case for an encyclopedia devoted to oceanography and meteorology, as illustrated here by the frequent reference to Vol. I. There do not seem to be many common problems of the atmospheric sciences and astrogeology, perhaps not surprising when astrogeology is itself a borderland of two disciplines, so that there appears to be two separate books interleaved by the accidents of the alphabetic entries. No doubt uniformity of size of the volumes played some part in the decision to produce this particular volume, and it would be unwise to comment until the series is completed. In any case the meteorologist will be glad of the glimpses that are afforded him by the non-meteorological text of a wide-ranging field of knowledge of planets, cosmology, relativity theory and so on. There are very substantial and readable essays on such subjects as the moon, the solar system and space science. Do these articles seem better written because one is far less familiar with their content?

There is no doubt that this volume will deservedly find its way on to every library shelf where meteorology is well represented, for despite my criticisms it is fundamentally a sound reference book.

E. KNIGHTING

Meteorology and atomic energy 1968, edited by David H. Slade. 200 mm × 260 mm pp. x+445, *illus.*, available as TID-24190 from Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U.S. Department of Commerce, Springfield, Virginia 22151, 1968. Price: $3·00.

It has been said* in reference to the peaceful application of nuclear energy: 'In history no technical conquest has ever been carried to a higher degree of safety and no other industry has caused so little damage to life and health.

* Dr E. J. Henningsen, Deputy Director-General, Danish National Health Service, W.H.O. seminar 1965: 'Protection of the public in the event of radiation accidents.'

Considering the predominantly injurious biological effects of radiation and the risk of severe accidents, it is surprising how safely radiation has been controlled and applied within different spheres of community life.'

There are very many aspects to this safety problem, and some of these involve meteorology. Meteorology enters first of all in the choice of site of a nuclear energy facility and its design and future operating character. Then in rather more exceptional cases it may be applied in day to day operations, especially at test sites, where routine releases may be large enough that certain meteorological conditions may seriously reduce the normally excellent dispersive character of the atmosphere. Concentrations then would involve risk if control were not applied. Finally, meteorology is inevitably involved in the unlikely event of an accident, so that human communities may be protected and areas of contaminated agricultural foodstuffs assessed.

This commendable book *Meteorology and atomic energy 1968* covers the whole problem, starting with a brief history of the atomic energy industry in the U.S.A., the development of safety measures and the meteorological theory on which these measures have been based. Although the eight chapters have been written by different authors, the whole work constitutes a very coherent and authoritative story which is clearly told, very readable and generously illustrated throughout. The first edition was written only 13 years ago in 1955 but in common with much of science, the advance within the subject has been so great that this second edition necessitated a complete rewrite. It thus brings together experimental data and theory that is up-to-date and can be found nowhere else in this form.

It is interesting for readers of the *Meteorological Magazine* to discover how very widely a practical technique for estimating diffusion of passive material from a continuous point-source in terms of broad stability conditions is now used. This was a method developed by Pasquill in 1958 in response to a request from the Atomic Energy Commission in Britain and it later appeared in these pages in 1961 when it was realized that a wider audience wished to use it. Its general success is now leading others to modify it for use in such specialized cases as, for example, dispersion over a city.

One of the most heartening advances described in this book is the emergence, after so many years of comparative confusion, of a really satisfactory description of the rise of buoyant plumes. Over twenty formulae for calculating plume rise have been published since 1950 and none of these have been universally accepted. Now Briggs has carried out a very thorough examination of most of the available data and with the help of dimensional analysis has begun to introduce order for the very first time. The account of this comparatively recent work is given in Chapter 5.

All in all, *Meteorology and atomic energy 1968* may be highly recommended to both seasoned scientists in this field and the new 'entrant' who requires a clear and comprehensive account. The price is very reasonable at $3.00 and my only regret is that, in this otherwise excellent production, the soft cover will surely not out last the continous handling the book is destined to receive.

F. B. SMITH

551.508.77:533.6.07:681.2.08

LETTERS TO THE EDITOR

Rain, wind and the aerodynamic characteristics of rain-gauges

We have read this paper[1] with interest and from our own recent field experiments would not disagree with the general conclusions to be drawn from Table II(*b*), namely that a ground-level gauge catches some 5 per cent more rain than the 5-in Mk 2 copper gauge; that the Mk 3 gauge catches about 3 per cent more than the Mk 2 gauge; that the Mk 4 gauge catches 5 per cent less than the Mk 2 gauge. (All gauges, except the ground-level gauge, have the standard exposure with rim at 1 ft (30 cm.). However, the paper raises more problems than it solves in so far as the reported wind-tunnel tests indicate that, of the Mk 2, Mk 3 and Mk 4 gauges, the latter presented the 'best' profile in so far as it caused the least disturbance to the wind field. As the authors suggest, the field result is therefore inconsistent with the wind-tunnel observations, implying that the latter are of doubtful value, certainly without additional refinement. More seriously, they lead to conclusions which field experience does not support. The Mk 4 gauge was adopted in preference to the Mk 3 gauge because the latter during field trials showed a significantly higher catch than the Mk 2 and the better profile of the Mk 4 was therefore logically expected to lead to an even higher catch, perhaps approaching that of a ground-level gauge. Further, the Mk 4 costs less to produce than the Mk 3. Needless to say, field experience has been disappointing, particularly as earlier tests of eliminated gauges similar in profile to the Mk 2 and Mk 4 showed a marked trend in favour of the latter.

The only way in which the field trials with the Mk 4 gauge could be made consistent with the wind-tunnel experiments reported here, would be to assume that the Mk 4 gauge is subject to out-splashing losses not compensated by any in-splashing. No evidence has been found that this in fact occurs and it is contrary to the expectation that the internal shape, approximating to that of a wine-glass or tulip. should be the best shape to avoid such losses.

In their second paragraph the authors state that certain differences (between gauges) may not be important to the meteorologist but are very significant to the hydrologist. This is so only in that the meteorologist (and presumably the hydrologist) is firstly concerned with consistency throughout a network as a first step towards accurate measurement. In considering the many measurements which enter into a quantitative water balance in an average catchment, it is as well to bear in mind that the rainfall determination, poor though it may be, is likely to be one of the most (if not the most) reliable observation.

Meteorological Office, Bracknell

A. BLEASDALE N. E. RIDER

REFERENCE

1. ROBINSON, A. C. and RODDA, J. C.; Rain, wind and the aerodynamic characteristics of rain-gauges. *Met. Mag., London*, **98**, 1969, p. 113.

551.509.322.7:311.214:629.13:681.3

The comparison of subjective and objective upper air forecasts for aviation (Part I).

Some queries have been made about the term 'polar curve' used in my article on 'Comparison of subjective and objective upper air forecasts for aviation' (*Met. Mag.*, **98**, 1969, p. 19). The route represented by 'polar curve' (e.g. Figure 1) is an arbitrary route decided upon in consultation with London/ Heathrow Airport, and can be described roughly as a reflection of the rhumb line in the great circle or a route which lies approximately as far north of the great circle as the rhumb line is south of the great circle.

I. H. CHUTER

OFFICIAL PUBLICATION

The following publication has recently been issued: *Tables of surface wind speed and direction over the United Kingdom.*

The 12 tables in this publication have been made possible because the number of stations for which analyses are available has increased. Table I presents average frequencies of wind speeds and of wind directions at 21 selected stations for the period 1950 to 1959. Table II contains means and maxima of the highest hourly wind speeds at 73 stations and Table III presents the means and maxima of the highest monthly gusts. Tables IV to IX give, for 43 anemograph stations, the average number of days in each month and the year on which gust speeds exceeded 33, 40, 50 and 60 knots and the average number of hours in each month and the year with gusts exceeding 33 and 47 knots. Table X consists of monthly and annual average percentage frequencies of hourly mean wind speeds and directions combined. Tables XI and XII give, for hourly mean speeds and gust speeds, maximum values likely to be exceeded only once in 10, 20, 50 and 100 years at 66 anemograph stations. These last two tables are obtained using the Gumbel theory of extreme values and as such present predictions of the extreme values and not, as in the preceding tables analyses of observations.

HONOURS

The following awards to members of the Meteorological Office were announced in the New Year's Honours List, 1969:

O.B.E.

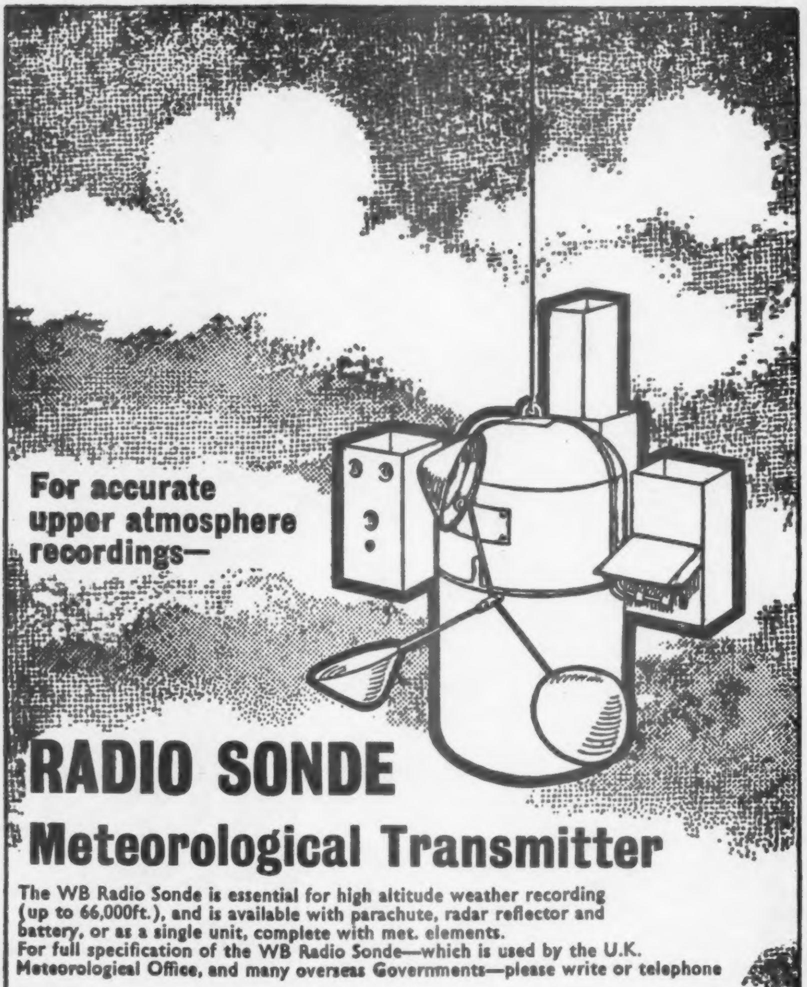
A. J. Willis, Chief Experimental Officer, Training Command, RAF.

M.B.E.

D. F. MacGregor, Shore Engineer, Ocean Weather Ships.

OBITUARY

It is with regret that we have to announce the death of Mr F. F. Harrington (X.O.) on 1 December 1968.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